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**Boutoussov et al.**

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(54) **ELECTROMAGNETIC ENERGY OUTPUT SYSTEM**

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**H01S 5/062** (2006.01)

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USPC ..... 606/1, 7, 13-16; 604/239, 240, 604/523-539; 607/88-92; 600/101-114; 128/898

See application file for complete search history.

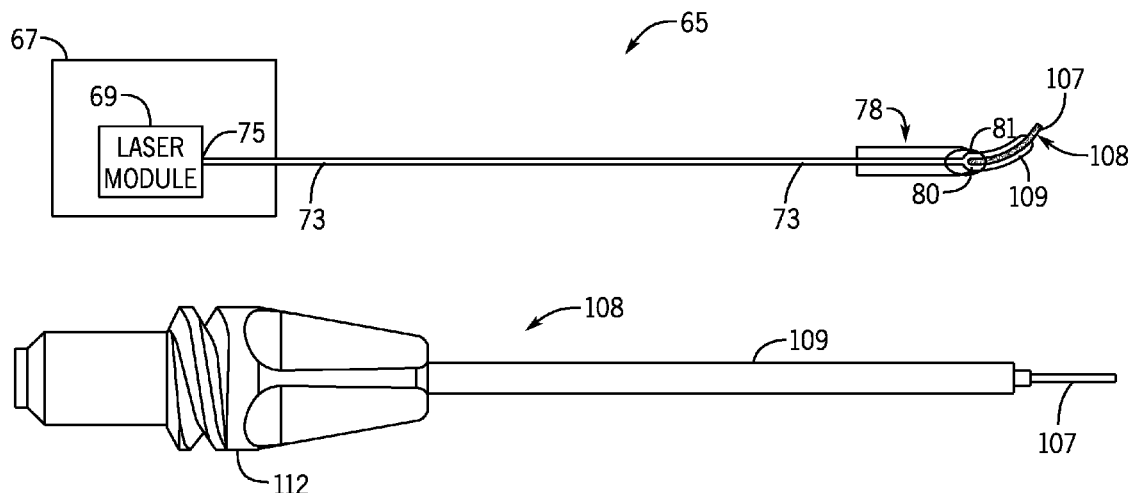
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(57) **ABSTRACT**

An apparatus having an excitation source that includes at least one laser diode and also having a handpiece with a disposable, bendable tip cannula is disclosed.

**18 Claims, 16 Drawing Sheets**



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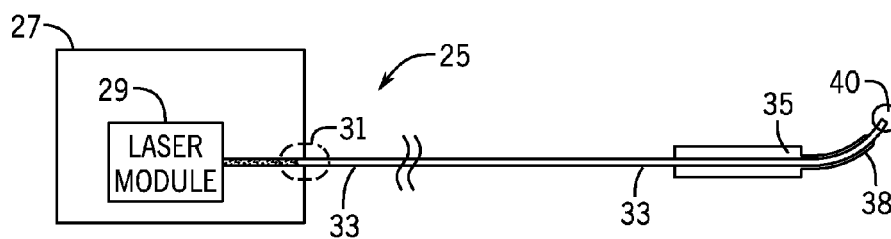


FIG. 1  
PRIOR ART

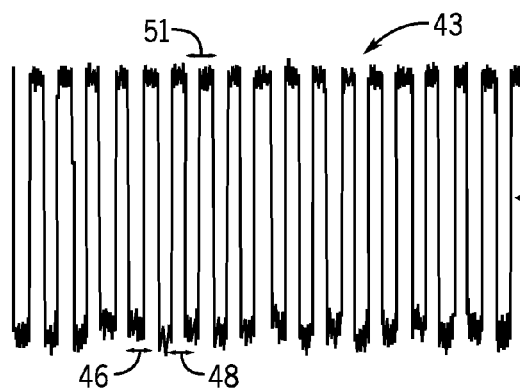


FIG. 2  
PRIOR ART

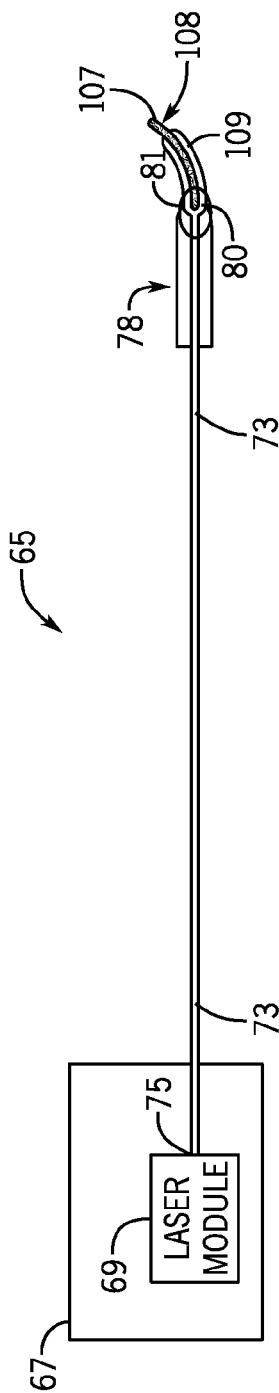


FIG. 3

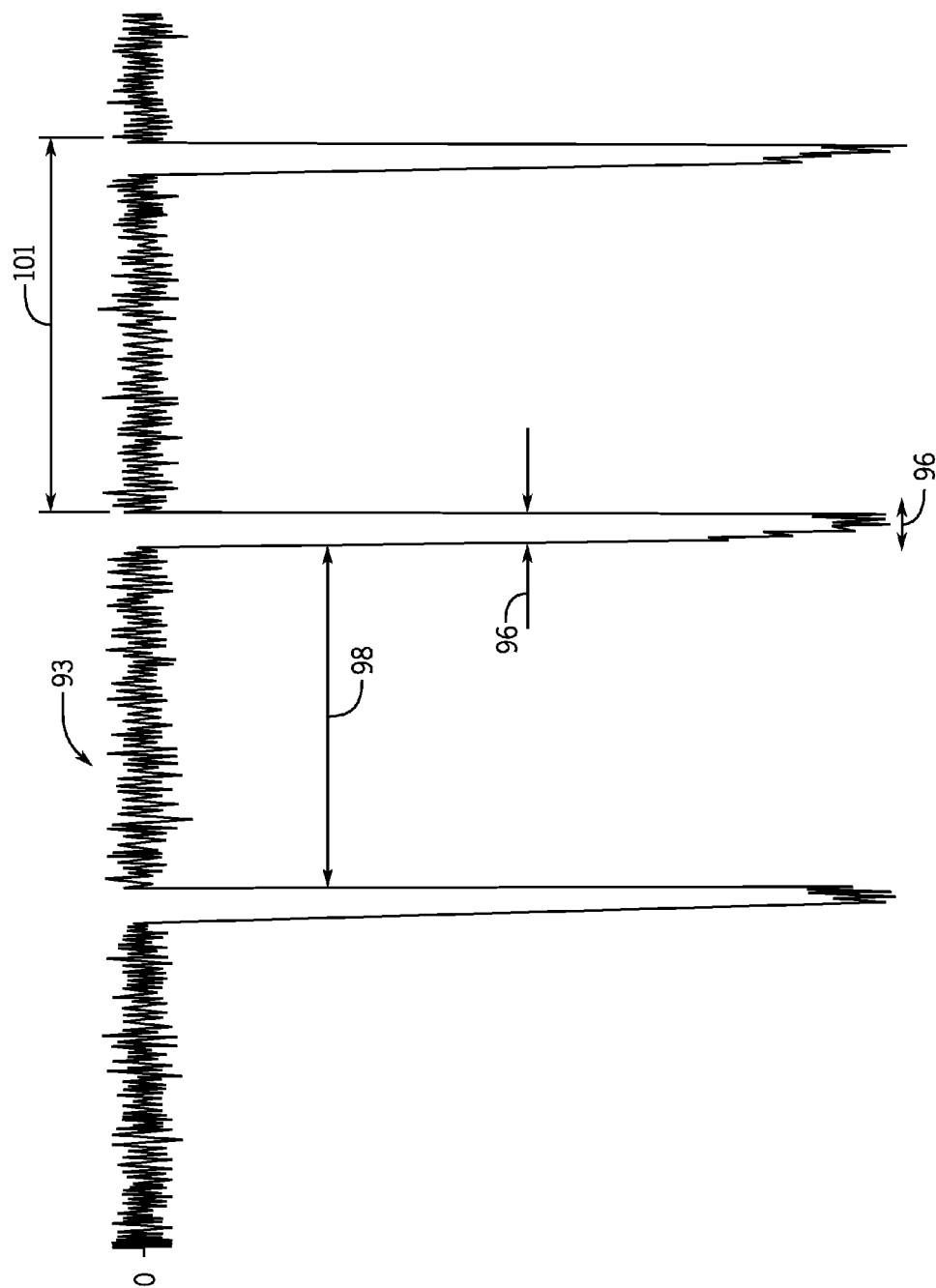


FIG. 4A

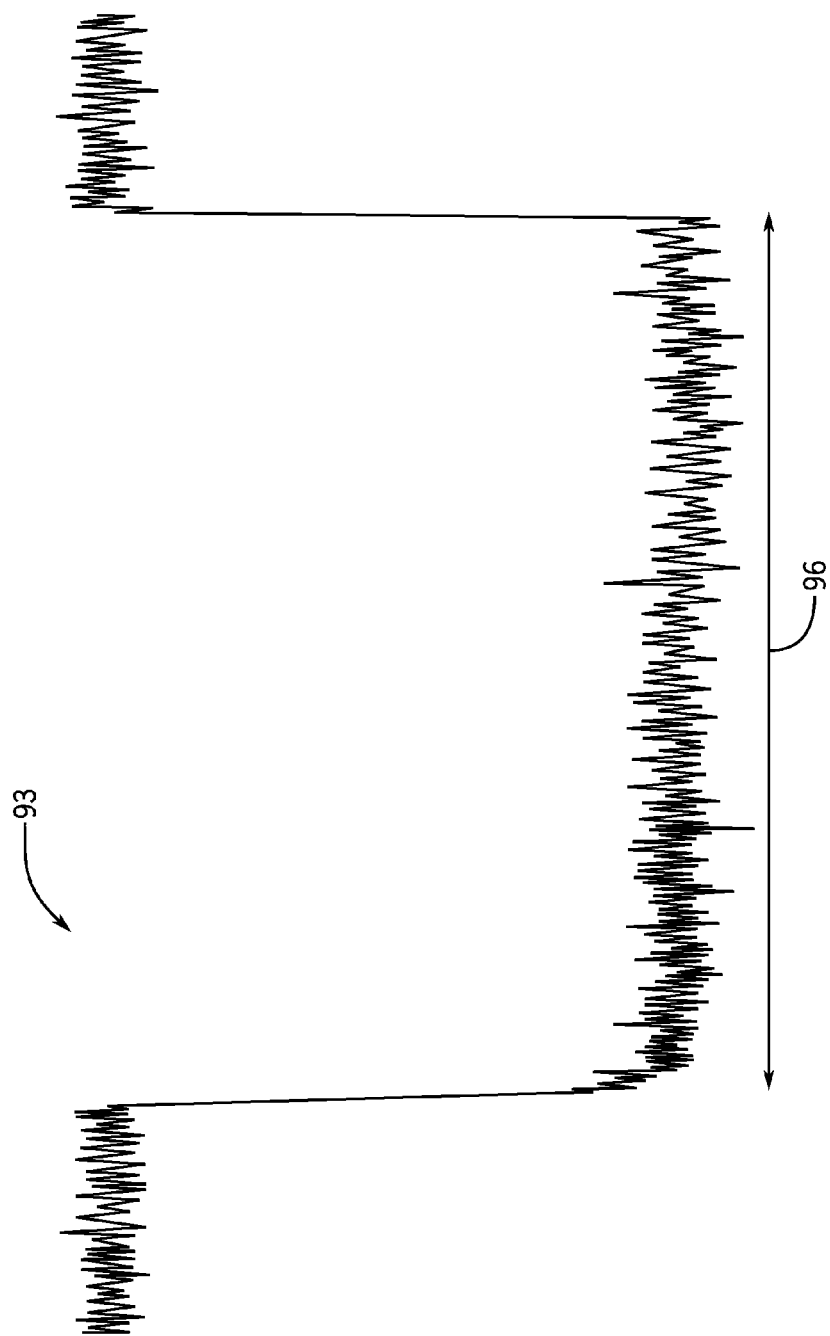


FIG. 4B

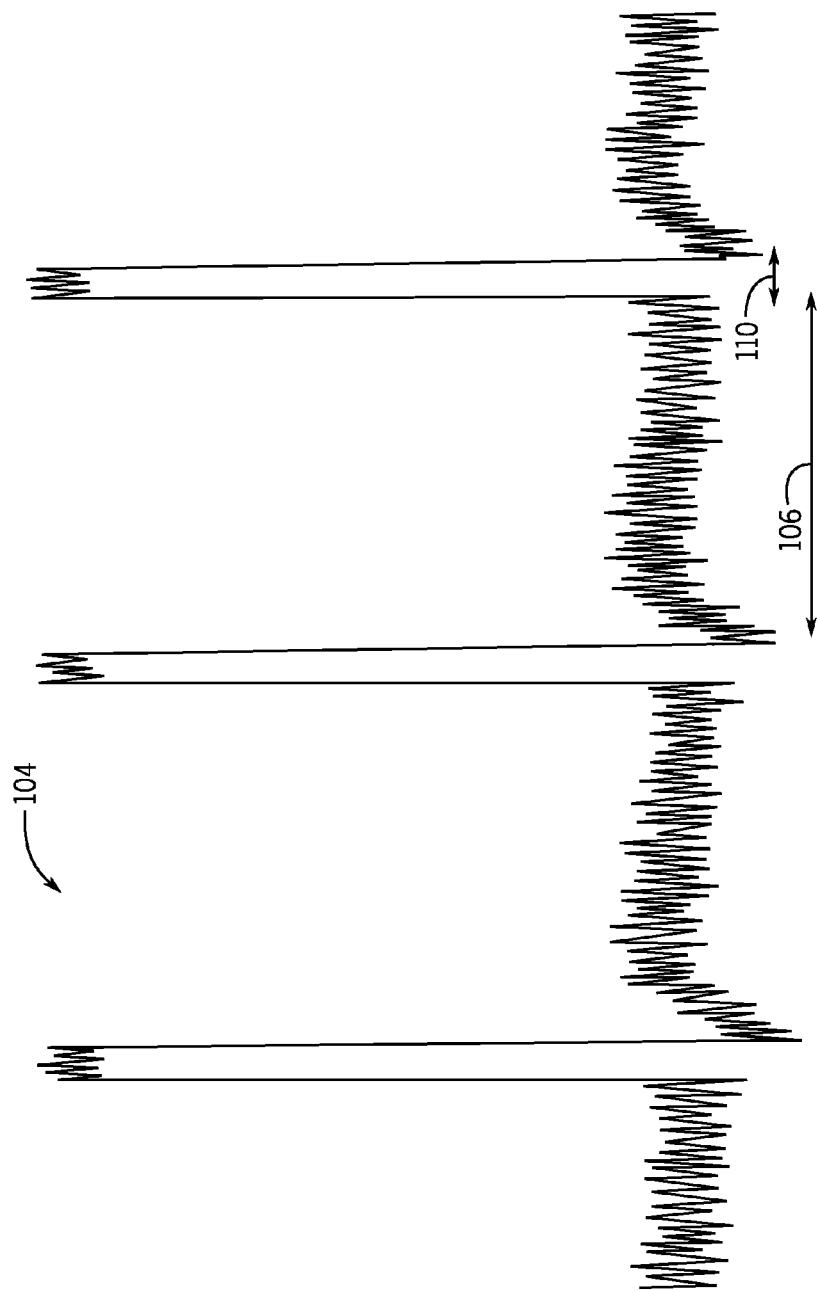


FIG. 5

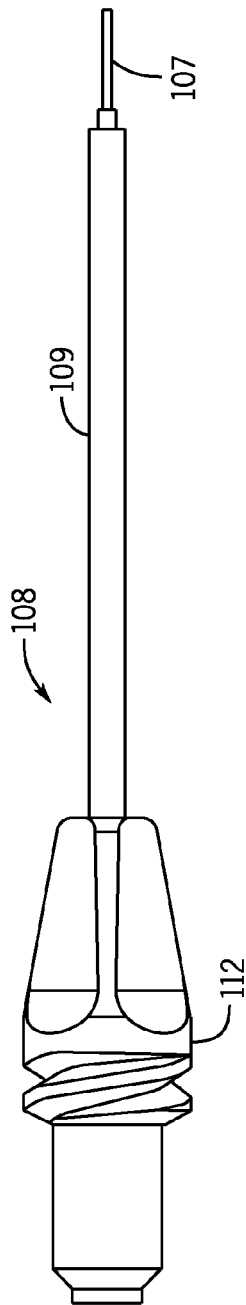


FIG. 6



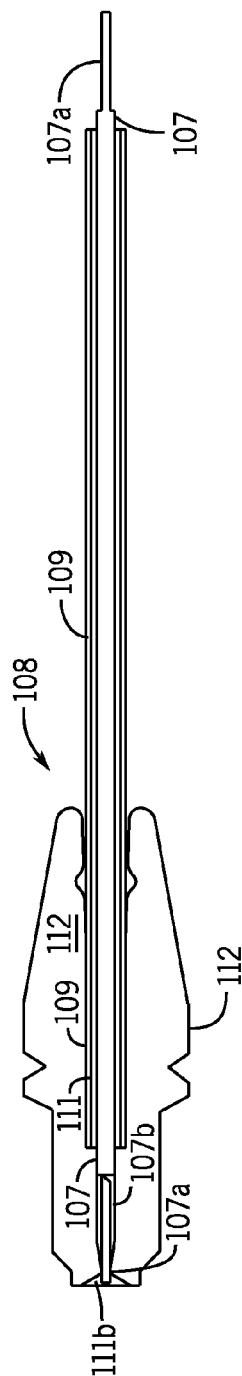


FIG. 7

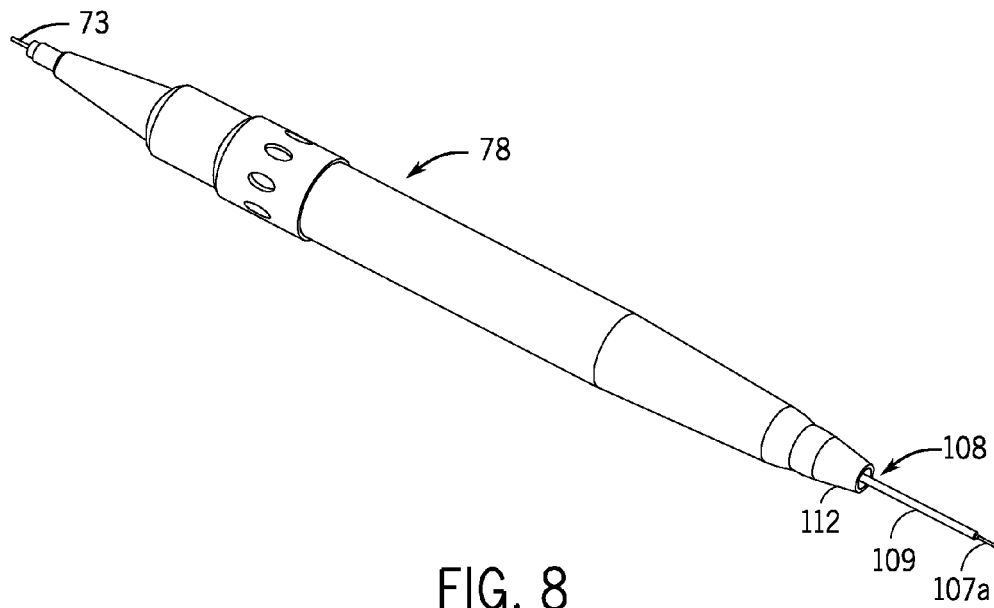


FIG. 8

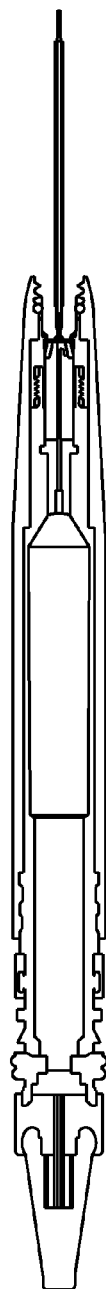


FIG. 9

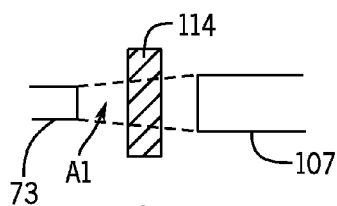


FIG. 11

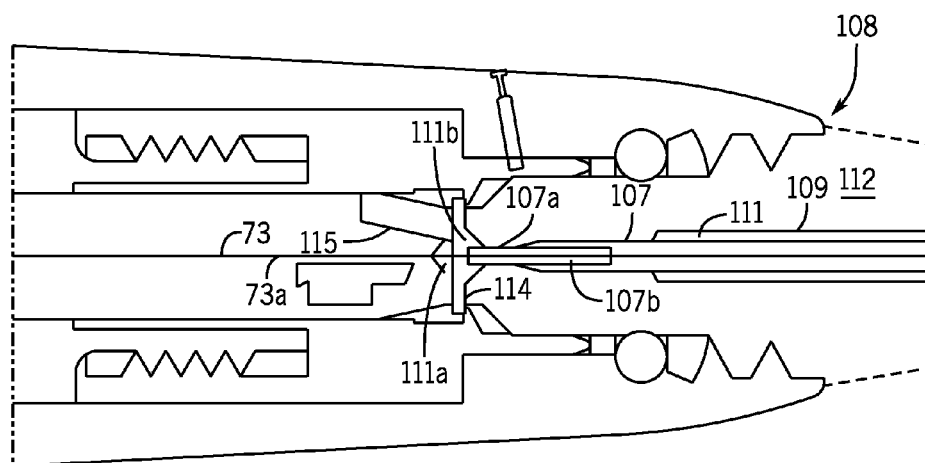


FIG. 10

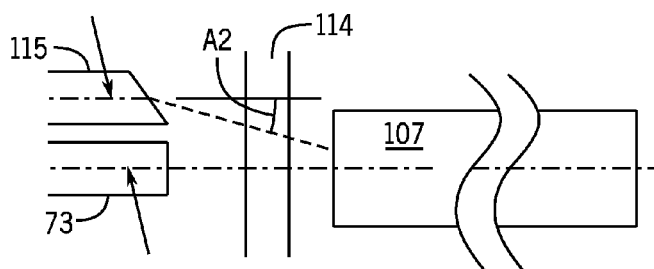


FIG. 12

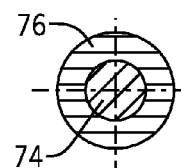


FIG. 13

TIPS TYPES


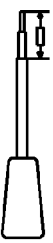
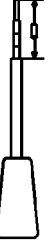





	TIP VIEW	NAME	CODE	CANNULA (TUBE)OD, mm	CANNULA (TUBE)LENGTH, mm	FIBER LENGTH, mm	TIP PRICE, \$	SURGICAL KIT	PERIO KIT	ENDO KIT	P / N FOR KIT
1		ezTIP SURGICAL, 400um	E4-4	1.3	15	4	8	25			74000XX
2		ezTIP PERIO, 7mm / 400um	E4-6	1.3	15	7	9		15		74000XX
3		ezTIP PERIO, 9mm / 400um	E4-9	1.3	15	9	10		10		
4		ezTIP SURGICAL, 300um	E3-4	1.1	15	4	8	25			74000XX
5		ezTIP PERIO, 7mm / 300um	E3-7	1.1	15	7	9		15		74000XX
6		ezTIP PERIO, 9mm / 300um	E3-9	1.1	15	9	10		10		
7		ezTIP SURGICAL, 200um	E2-4	0.9	15	4	8	25			74000XX
8		ezTIP ENDO, 14mm / 200um	E2-14	0.9	15	14	12			25	74000XX

FIG. 14

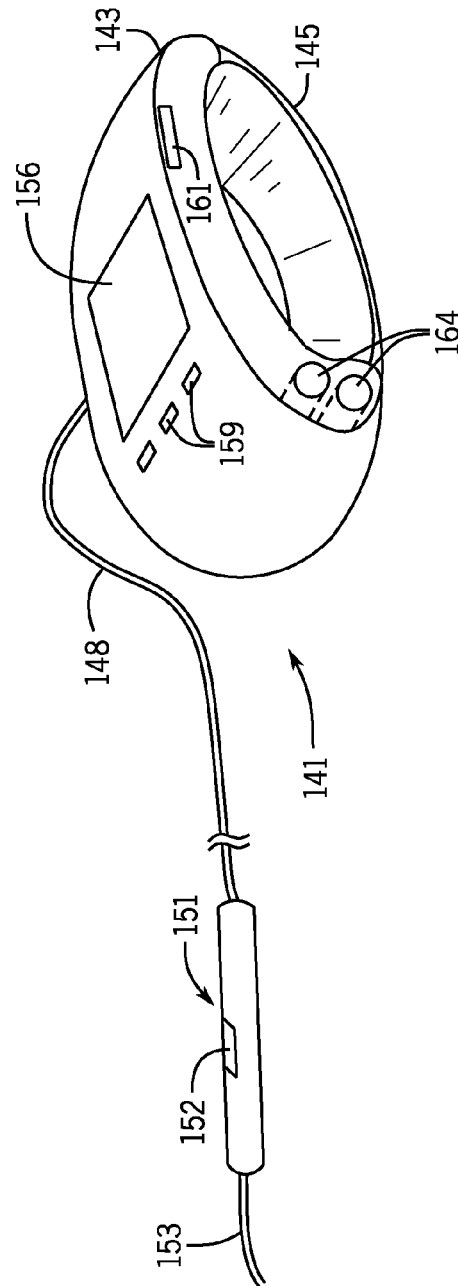


FIG. 15

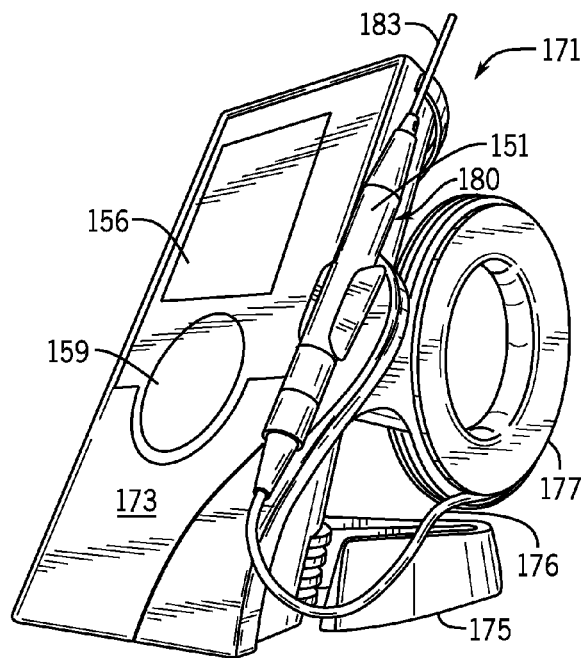


FIG. 16

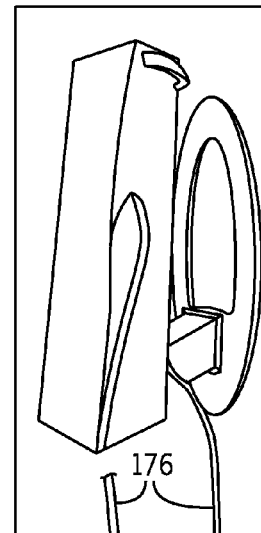


FIG. 18

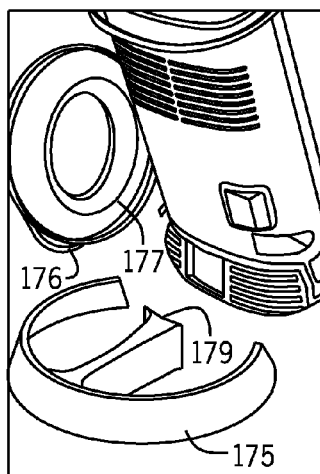


FIG. 19

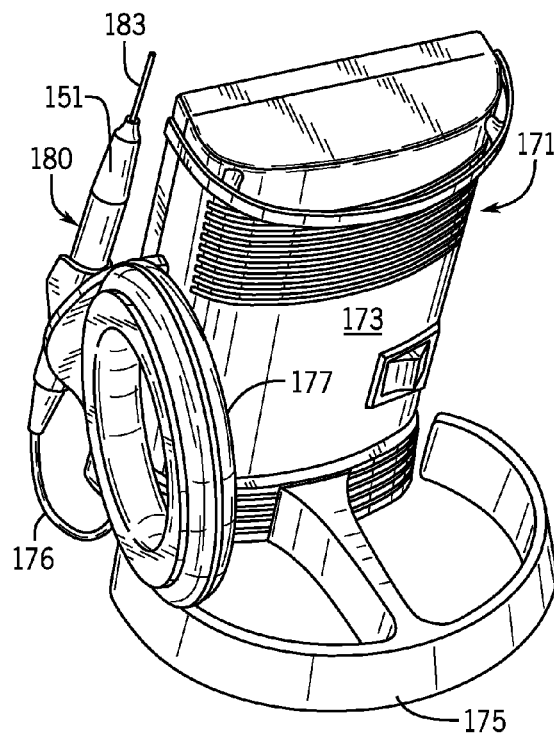


FIG. 17

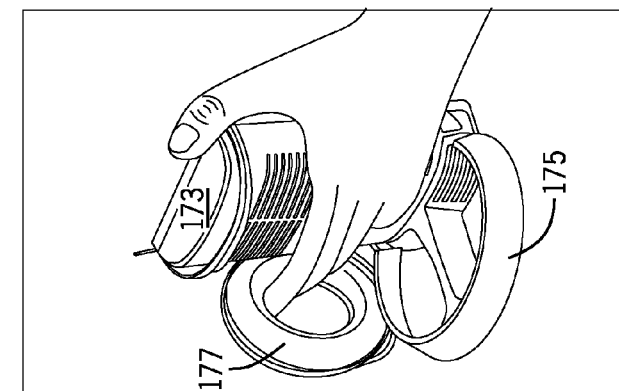


FIG. 20B

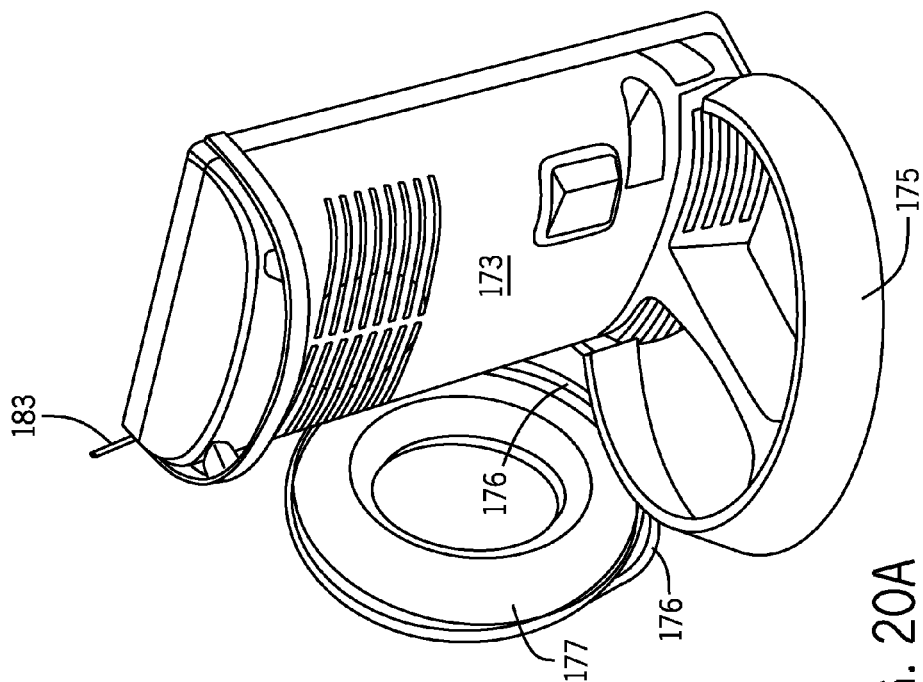


FIG. 20A



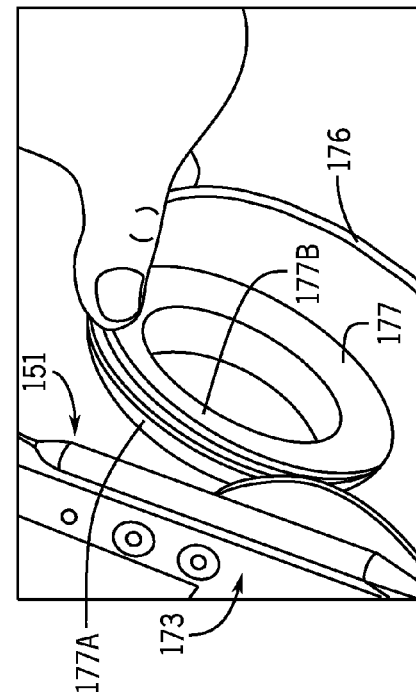


FIG. 21

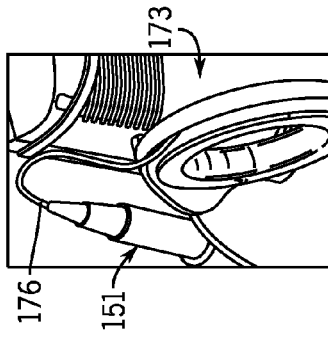


FIG. 22

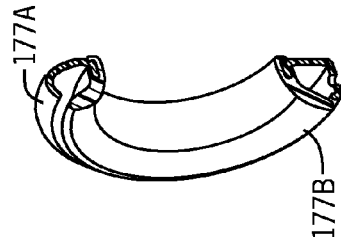


FIG. 23

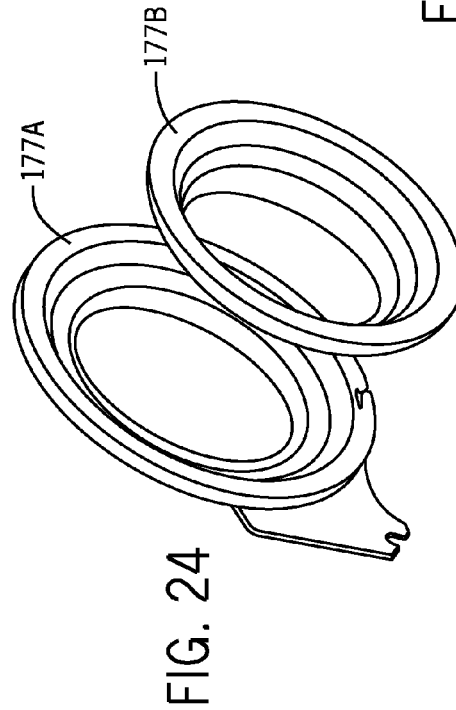


FIG. 24

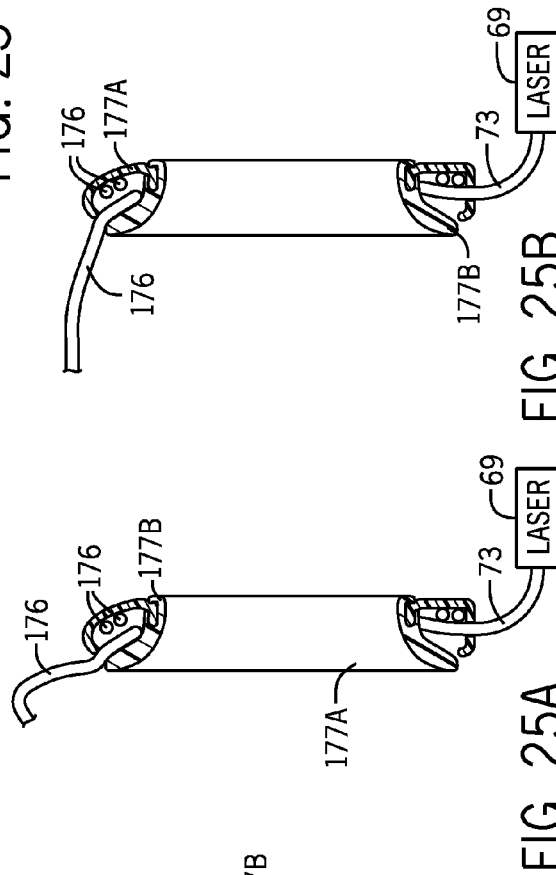


FIG. 25A

FIG. 25B

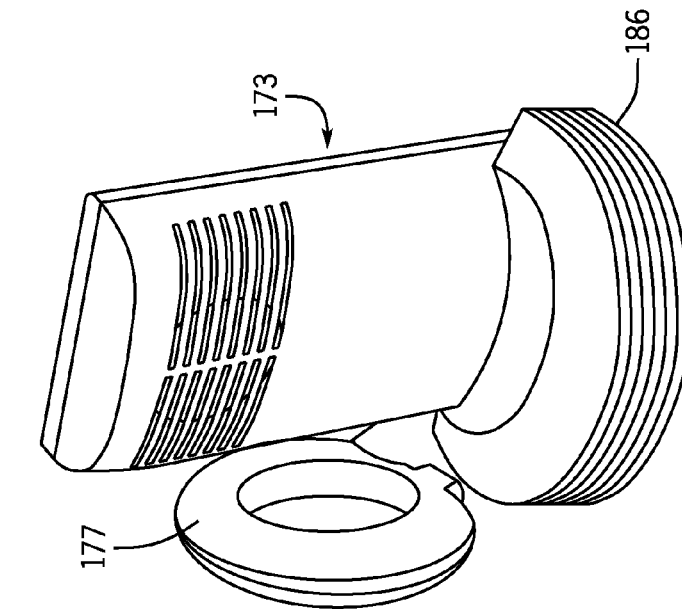


FIG. 26B

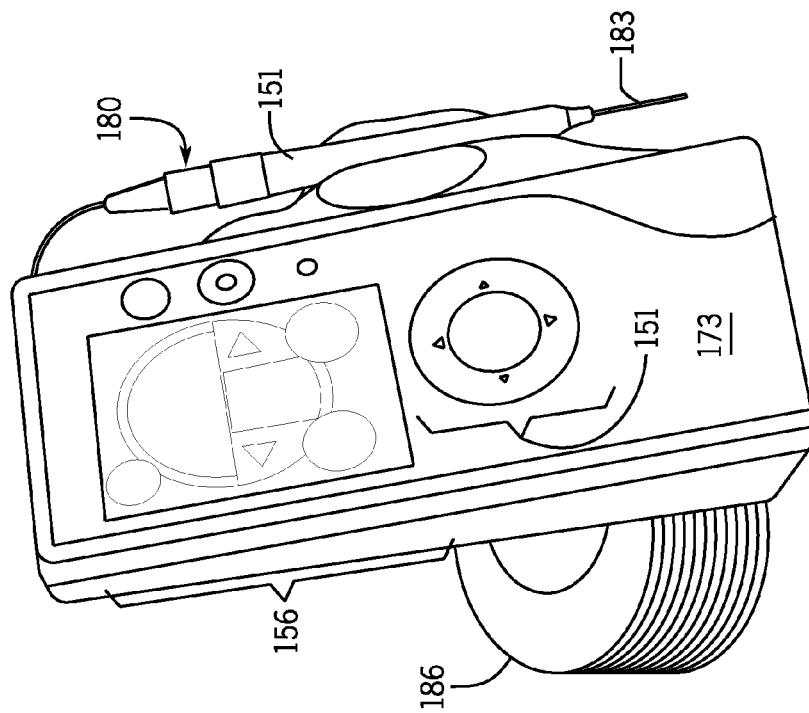


FIG. 26A

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ELECTROMAGNETIC ENERGY OUTPUT  
SYSTEM

## BACKGROUND OF THE INVENTION

## 1. Field of the Invention

The present invention relates generally to devices for generating output optical energy distributions and, more particularly, to lasers.

## 2. Description of Related Art

A variety of laser systems have existed in the prior art. A solid-state laser system generally comprises a laser rod for emitting coherent light and a stimulation source for stimulating the laser rod to emit the coherent light. Flashlamps are typically used as stimulation sources for laser systems, for example, but diodes may be used as well for the excitation source. The use of diodes for generating light amplification by stimulated emission is discussed in the book *Solid-State Laser Engineering*, Fourth Extensively Revised and Updated Edition, by Walter Koechner, published in 1996, the contents of which are expressly incorporated herein by reference.

With reference to FIG. 1, a conventional laser assembly 25 may comprise a housing 27 containing a laser module 29, which is connected by way of an optical connector 31 to a trunk fiber 33. The optical connector 31 is typically disposed within and concealed by a portion of the housing 27 and, further, is typically constructed to facilitate attachment and removal of the trunk fiber 33 to and from the housing 27. Moreover, in the illustrated prior-art example, the trunk fiber 33 extends in an uninterrupted fashion from the housing 27 up to and through a handpiece 35. Furthermore, the trunk fiber 33 continues in an uninterrupted fashion from the handpiece 35 through a pre-bent tip cannula 38 and terminates at an energy output end 40 of the trunk fiber 33. The pre-bent tip cannula 38 comprises a rigid plastic or a stainless steel material.

A spool (not shown) can be disposed in close proximity to the optical connector 31, for storing extra trunk fiber 33. The spool can be secured to the housing 27 to provide a user with access and to enable the user to increase a length of the trunk fiber 33 by advancing additional trunk fiber 33 from the spool toward the handpiece 35. In typical implementations, the energy output end 40 of the trunk fiber 33 can exhibit signs of wear or damage after use, and thus should be replaced on a regular and frequent basis. To this end, after each use, the user will typically need to cleave a portion (e.g., between 3 and 10 millimeters) off of the energy output end 40 of the trunk fiber 33 and advance an additional length of trunk fiber 33 from the spool to compensate for the decrease in length of the trunk fiber 33 caused by the cleaving. Of course, to facilitate this functionality, the trunk fiber 33 must be slidably disposed, and cannot be permanently affixed such as by an adhesive, within the pre-bent tip cannula 38. Using this technique, a trunk fiber 33 length of, for example, 10 to 12 feet can be maintained. Additionally, for sanitation purposes, the pre-bent tip cannula and any other appropriate components are typically sterilized, such as by autoclaving, on a regular and frequent basis.

FIG. 2 illustrates a plot of energy versus time for an output optical energy waveform 43 of a prior-art laser, such as the conventional laser assembly 25 depicted in FIG. 1. The output optical energy waveform 43 may be generated by a compact diode laser, such as a SIROLaser, manufactured by Sirona Dental Systems GmbH, of Germany, having a URL of [www.sirona.com](http://www.sirona.com), operable at a wavelength of 980 nanometers and a repetition rate of about 10 kHz, and having an average power output, defined as the power delivered over a predetermined period of time, varying from 0.5 to 7 W. Each pulse of

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the depicted output optical energy waveform 43 has a pulse duration 46 and a pulse interval 48. In the illustrated example, the output optical energy waveform 43 can be generated such that the pulse duration 46 can have a value of about 50 microseconds and the pulse interval 48 can also have a value of about 50 microseconds. According to the exemplary depiction, the output optical energy waveform 43 can be said to have a pulse period 51 of about 100 microseconds, and, furthermore, the output optical energy waveform 43 can be said to have a pulse duty cycle, defined as the pulse duration 46 divided by the pulse interval 48, of about 50%. The pulse duration 46 and the pulse duration 48 of this exemplary prior-art system cannot be independently adjusted.

Another prior-art system is the LaserSmile™ laser, manufactured by BIOLASE Technology, Inc., of Irvine, Calif., having a URL of [www.biolase.com](http://www.biolase.com). This laser can be operated at a wavelength of 810 nanometers and a repetition rate of, for example, about 0.01 to about 5 Hz, with corresponding pulse durations of about 0.02 to about 9.9 seconds, and with an average power output up to about 10 W. Output optical energy waveforms from the laser can have pulse duty cycles of, for example, between 10% and 50%. Additionally, while being independently adjustable, the pulse duration and pulse interval of the laser's output optical energy waveform tend to be relatively large and not adequately or optimally suited for a number of soft tissue cutting procedures, such as procedures designed to minimize an impartation of thermal energy into the target soft tissue.

## SUMMARY OF THE INVENTION

The present invention provides an apparatus having an excitation source that includes at least one laser diode and also having a handpiece with a disposable, bendable tip cannula.

While the apparatus and method have or will be described for the sake of grammatical fluidity with functional explanations, it is to be expressly understood that the claims, unless expressly formulated under 35 USC 112, are not to be construed as necessarily limited in any way by the construction of "means" or "steps" limitations, but are to be accorded the full scope of the meaning and equivalents of the definition provided by the claims under the judicial doctrine of equivalents, and in the case where the claims are expressly formulated under 35 USC 112 are to be accorded full statutory equivalents under 35 USC 112.

Any feature or combination of features described herein are included within the scope of the present invention provided that the features included in any such combination are not mutually inconsistent as will be apparent from the context, this specification, and the the knowledge of one skilled in the art. In addition, any feature or combination of features may be specifically excluded from any embodiment of the present invention. For purposes of summarizing the present invention, certain aspects, advantages and novel features of the present invention are described. Of course, it is to be understood that not necessarily all such aspects, advantages or features will be embodied in any particular implementation of the present invention. Additional advantages and aspects of the present invention are apparent in the following detailed description and claims that follow.

## BRIEF DESCRIPTION OF THE FIGURES

FIG. 1 shows a conventional laser assembly;

FIG. 2 illustrates a plot of energy versus time for an output optical energy waveform of a prior-art laser;

FIG. 3 depicts an electromagnetic energy output device according to the present invention;

FIGS. 4A and 5 illustrate plots of energy versus time for output optical energy waveforms, according to the present invention, that can be outputted by an electromagnetic energy output system such as the laser module depicted in FIG. 3;

FIG. 4B is a magnified view of the plot of energy versus time for the output optical energy waveform of FIG. 4A;

FIG. 6 is a side-elevation view of an exemplary output tip comprising an output fiberoptic, a bendable tip cannula, and a ferrule;

FIG. 7 is a cross-sectional view of the output tip shown in FIG. 6;

FIG. 8 is a side-elevation view of the output tip of FIG. 6 connected to a handpiece;

FIG. 9 is a cross-sectional view of the assembly of FIG. 8;

FIG. 10 a magnified view of portions of the structure of FIG. 9;

FIG. 11 is a schematic representation of the portion depicted in FIG. 10;

FIG. 12 is a schematic representation of the portion depicted in FIG. 10 according to a modified embodiment;

FIG. 13 depicts an irradiation pattern that may be generated and output from the embodiment of FIG. 12;

FIG. 14 shows examples of a number of typical bendable tip cannulas according to the present invention;

FIG. 15 depicts a body-mount implementation of an electromagnetic energy output device according to an aspect of the present invention;

FIGS. 16 and 17 are perspective front and rear views, according to an aspect of the present invention, of an electromagnetic energy output device in the form of a compact, portable assembly that can be carried or mounted with relative ease by a user.

FIG. 18 shows the electromagnetic energy output device of FIGS. 16 and 17 in a wall-mount configuration according to an aspect of the present invention;

FIG. 19 shows the electromagnetic energy output device of FIGS. 16 and 17 with a detached base according to an aspect of the present invention;

FIG. 20A shows the electromagnetic energy output device of FIGS. 16 and 17, disposed on a flat surface such as a table top according to an aspect of the present invention;

FIG. 20B is a rear view of the electromagnetic energy output device of FIGS. 16 and 17, held by a hand of a user according to another aspect of the present invention;

FIGS. 21-25B depict various perspective views of spool structures and associated techniques corresponding to aspects of the present invention; and

FIGS. 26A-26B depict front and rear perspective views of a modified-base implementation according to an aspect of the present invention.

### DETAILED DESCRIPTION OF THE PRESENT INVENTION

Reference will now be made in detail to particular embodiments of the invention, examples of which are illustrated in the accompanying drawings. Wherever possible, the same or similar reference numbers are used in the drawings and the description to refer to the same or like parts. It should be noted that the drawings are in simplified form and are not to precise scale. In reference to the disclosure herein, for purposes of convenience and clarity only, directional terms, such as, top, bottom, left, right, up, down, over, above, below, beneath, rear, and front, are used with respect to the accompanying

drawings. Such directional terms should not be construed to limit the scope of the invention in any manner.

Although the disclosure herein refers to certain illustrated embodiments, it is to be understood that these embodiments are presented by way of example and not by way of limitation. The intent of this disclosure, while discussing exemplary embodiments, is that the following detailed description be construed to cover all modifications, alternatives, and equivalents of the embodiments as may fall within the spirit and scope of the invention as defined by the appended claims.

An electromagnetic energy output device is disclosed for implementing procedures on hard or soft tissue. The electromagnetic energy output device can be configured, for example, to be particularly suited for soft tissue cutting or ablating procedures, and also for decontamination, cleaning periodontal pockets, pain reduction, and biostimulation procedures.

With reference to FIG. 3, an embodiment of the current invention comprises an electromagnetic energy output device 65 having a system 67, such as a diode laser system. The system 67 in the illustrated embodiment can comprise a laser module 69, which, in accordance with one aspect of the present invention, can be directly coupled to a trunk optical fiber 73. According to one implementation and one aspect of the invention, the trunk optical fiber 73 can be permanently coupled to the system 67. According to another embodiment and aspect of the invention, the trunk optical fiber 73 can also, or alternatively, be permanently coupled to the laser module 69 within the system 67.

The trunk optical fiber 73 in the illustrated embodiment, and according to another aspect of the invention, extends from a permanent connection 75 at the laser module 69 all of the way to a handpiece 78. Furthermore, in a typical embodiment, the trunk optical fiber 73 extends a further distance through at least a part of the handpiece 78. In the illustrated embodiment, the trunk optical fiber 73 extends through substantially all of the handpiece 78 and terminates at an energy output end 80 of the trunk fiber 73, in a vicinity of a distal handpiece end 81 of the handpiece 78.

A diode (not shown) within the laser module 69 can be driven by a diode current, which can comprise a predetermined pulse shape and a predetermined frequency. The diode current can drive a diode, or diode array, at the predetermined frequency, to thereby produce an output diode light distribution having, for example, substantially the same frequency as the diode current. This output diode light distribution from the diode can drive a laser rod (not shown) to produce coherent light at substantially the same predetermined frequency as the diode current. The coherent light generated by the laser rod can have, for example, an output optical energy distribution over time that generally corresponds to the pulse shape of the diode current. The pulse shape of the output optical energy distribution over time typically comprise a relatively steep rising energy that ramps to a maximum energy level followed by a subsequent decreasing energy over time.

The laser module 69 may comprise a solid-state laser rod pumping module and a stack-type semiconductor laser. The semiconductor laser can be based on a semiconductor gain media, where optical gain is generally achieved by stimulated emission at an interband transition under conditions of an inversion (i.e., high carrier density in the conduction band). The semiconductor laser can be a laser diode, which is pumped by an electrical current in a region where n-doped and p-doped semiconductor materials meet. In certain embodiments, optically pumped semiconductor lasers, where carriers are generated by absorbed pump light, can be used. In the case of, for example, a stack-type semiconductor laser, it

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can include a plurality of bar-shaped components that are stacked in a direction parallel to the axis of a solid-state laser rod. Each bar-shaped component can include a plurality of laser-light-emitting portions that are aligned and integrated in a direction orthogonal to the orthogonal to the axis of the solid-state laser rod. The large divergence angle of the stack-type semiconductor can be compensated by including a light focusing component for focusing laser light emitted out of the stack-type semiconductor laser, and the focused light can be guided by a laser light guiding component disposed in a diffusive reflection tube. Thus, a light guiding component can guide focused light onto the solid-state laser rod located within the diffusive reflective tube, while maintaining the length of one side of the cross section of the guided light.

The semiconductor laser or other optoelectronic device can comprise, for example, a Indium Gallium Arsenide (GaAs) material. In an exemplary implementation, the gain medium can comprise a laser rod, such as a configuration comprising an active heterostructure and substrate of AlGa(In)As/GaAs, wherein the Ga of the active heterostructure can be substituted for and/or combined with In. Another exemplary implementation can comprise AlGaInP(As)/GaAs, wherein the P of the active heterostructure can be substituted for and/or combined.

FIG. 4A illustrates a plot of energy versus time for an output optical energy waveform 93, according to the present invention, that can be outputted by an electromagnetic energy output system, such as the laser module 69 depicted in FIG. 3. FIG. 4B is a magnified view of the plot of energy versus time for the output optical energy waveform 93 of FIG. 4A.

Each of the pulses of the output optical energy waveform 93 comprises a plurality of micropulses. The micropulses correspond to population inversions within the laser rod as coherent light is generated by stimulated emission. Particles, such as electrons, associated with impurities of the laser rod absorb energy from the impinging incoherent radiation and rise to higher valence states. The particles that rise to metastable levels remain at this level for periods of time until, for example, energy particles of the radiation excite stimulated transitions. The stimulation of a particle in the metastable level by an energy particle results in both of the particles decaying to a ground state and an emission of twin coherent photons (particles of energy). The twin coherent photons can resonate through the laser rod between mirrors at opposing ends of the laser rod, and can stimulate other particles on the metastable level, to thereby generate subsequent twin coherent photon emissions. This process is referred to as referred to as light amplification by stimulated emission. With this process, a twin pair of coherent photons will contact two particles on the metastable level, to thereby yield four coherent photons. Subsequently, the four coherent photons will collide with other particles on the metastable level to thereby yield eight coherent photons.

The amplification effect will continue until a majority of particles, which were raised to the metastable level by the stimulating incoherent light from the diode, have decayed back to the ground state. The decay of a majority of particles from the metastable state to the ground state results in the generation of a large number of photons, corresponding to an upwardly rising micropulse. As the particles on the ground level are again stimulated back up to the metastable state, the number of photons being emitted decreases, corresponding to a downward slope in the micropulse. The micropulse continues to decline, corresponding to a decrease in the emission of coherent photons by the laser system. The number of particles stimulated to the metastable level increases to an amount where the stimulated emissions occur at a level sufficient to

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increase the number of coherent photons generated. As the generation of coherent photons increases, and particles on the metastable level decay, the number of coherent photons increases, corresponding to an upwardly rising micropulse.

The output optical energy waveform 93 according to an aspect of the invention is generated by a diode laser to have a wavelength, pulse, and power density suitable for cutting and ablating, for example, soft tissue. The diode light pump or the at least one diode can comprise a diode array, and the diode or diode array can be optically aligned to side pump the gain medium. In one implementation, the diode light pump can be placed, for example, within an optical cavity so that the diode or diode array is optically aligned to side pump the gain medium. Generation of the output optical energy waveform 93 can be accomplished, for example, in the TEM<sub>00</sub> mode to attenuate or overcome thermal effects.

With reference to FIGS. 4A and 4B, the output optical energy waveform 93 according to an aspect of the invention is generated by a diode laser to have a wavelength of 940 nanometers, and can be delivered, for example, in a CW (continuous wave) or a QCW (quasi-continuous wave) mode of operation. As presently embodied, the output optical energy waveform 93 is delivered in a pulsed-format mode of operation that is highly repetitive in time and intensity to provide, for example, relatively precise and predictable cutting. As compared, for example, to a wavelength of 810 nanometers, with other things being equal, the wavelength of 940 nanometers has been determined by the present inventors to have an absorption that is about four times greater for water, two times greater for hemoglobin (for enhanced homeostasis) and about 20% greater for oxyhemoglobin. Alternative wavelengths which can be used according to modified aspects of the present invention can be, for example, 915 nanometers, 960 nanometers and 980 nanometers. Other alternative wavelengths which can be used in other modified aspects of the invention can comprise the mentioned wavelengths, plus or minus about 50 nanometers.

As shown in FIG. 4A, each pulse of the output optical energy waveform 93 can comprise, for example, a pulse duration 96 of about 50 microseconds, a pulse interval 98 of about 450 microseconds, and a pulse period of about 500 microseconds. The magnified view of a pulse featured in FIG. 4B shows that the pulse duration 96 has room for being further reduced in duration. For example, the pulse duration 96 can, according to certain embodiments, be reduced from about 50 microseconds all of the way down to about 10 microseconds. Thus, as illustrated, the output optical energy waveform 93 can comprise a repetition rate of about 2 kHz. The repetition rate can also be, for example, about 10 kHz, corresponding to a pulse period of about 100 microseconds. The full-width half-max of the pulse may be about 50 to 100 microseconds. The depicted output optical energy waveform 93 thus has a pulse duration 96 and a pulse interval 98 which are both on the order of microseconds. The pulse period is indicated with reference designator number 101 in the depiction of FIG. 4A. FIG. 5 shows an output optical energy waveform 104 comprising, for example, a pulse duration 106 of about 500 microseconds and a pulse interval 110 of about 50 microseconds.

According to the present invention, the system 67 of the current invention can be configured to implement output optical energy waveforms 93 that minimize an impartation of thermal energy into the target tissue (e.g., soft tissue). As an example, the thermal diffusion time, or thermal relaxation time, for soft tissue is about 150 to 200 microseconds. Thus, according to an aspect of the present invention, for certain applications, the pulse duration of the optical beam (e.g., the output optical energy waveforms 93) can be

approximately equal to or less than the thermal relaxation time, which may be approximately proportional to the square of the diameter of the focal spot on or within the treatment area. Pulse durations that are longer than the thermal relaxation time can be less efficient and cause the spot to undesirably grow or shrink by thermal diffusion. In one implementation, the pulse duration is set to have a value (e.g., 50 microseconds) that is less than the thermal relaxation time. In another implementation, the pulse interval is set to have a value (e.g., 450 microseconds) that is equal to or greater than the thermal relaxation time. Another implementation can comprise a combination of these two aspects, wherein the pulse duration can be set to be below the thermal relaxation time and the pulse interval can be set to be equal to or greater than the thermal relaxation time.

According to another aspect of the present invention, the output optical energy waveform **93** can be varied by way of independent adjustments to one or more of the pulse duration **96** and the pulse interval **98**. By way of providing independent adjustments to one or more of the pulse duration **96** and the pulse interval **98**, and, preferably, both, the pulse duty cycle, defined as the pulse duration **96** divided by the pulse interval **98**, can be controlled. As presently embodied, the pulse duty cycle can be adjusted from, for example, about 10% to about 50%. Thus, the pulse duration can be set, independently of, for example, the pulse interval, to have a value (e.g., 50 microseconds) that is below the thermal relaxation time; the pulse interval can be set, independently of, for example, the pulse duration, to have a value (e.g., 450 microseconds) that is equal to or longer than the thermal relaxation time; and/or the pulse duration and pulse interval can be set to be below, and equal to or greater than, the thermal relaxation time, respectively, to approach or achieve, for example, a characteristic referred to as cold cutting.

Setting of the pulse duration and pulse interval as described in the foregoing paragraph can facilitate a type of cold-cutting tissue interaction. Cold cutting may bring about certain characteristics or advantages, as discussed below, while, on the other hand, non cold-cutting modes, or intermediate modes, may bring about additional characteristics or advantages, a few advantages, a few of which are discussed below.

By controlling one or more of the pulse duration **96** and the pulse interval **98**, various procedural properties, such as bleeding, can be controlled. For example, increasing the pulse duration independent of, for example, the pulse repetition rate, can operate to decrease bleeding or increase coagulation, as a result of providing a greater thermic effect to the target. The effect of such a mode (e.g., a thermic effect, which may tend, for example, to augment coagulation) can in some instances create greater scar tissue and/or impede the speed or quality of healing of a target. On the other hand, generating a cooler-cutting (e.g., cold cutting) effect, by, for example, outputting optical energy waveform **93** with a reduced pulse duty cycle (and/or, for example, setting the pulse duration and/or pulse interval below, and/or equal to or greater than, the thermal relaxation time, respectively, as described herein) may enable a treated region to heal better or faster, and/or may facilitate implementation of a procedure with less pain to the patient.

Referring back to FIG. 3, an optical interface can be disposed at a termination of the trunk optical fiber **73** near the distal handpiece end **81**, wherein the optical interface can be constructed to provide an optical pathway between the trunk optical fiber **73** and an output fiberoptic **107** of an output tip **108**. Thus, as presently embodied, the trunk fiber **73** can extend in an uninterrupted fashion from the system **67** up to

and through the handpiece **78**, terminating at or near the optical interface, which, in turn, can be located at or near the handpiece distal end **81**.

The optical interface can be disposed, for example, within and concealed within the handpiece distal end **81** as illustrated. The output tip **108** can be removable in accordance with an aspect of the present invention. In a number of such embodiments, the handpiece distal end **81** and the output tip **108** can be constructed to interact in such a way as to facilitate convenient and rapid attachment and removal of the output tip **108** to and from the handpiece **78**. The output tip **108** can additionally, or alternatively, be removed and interchanged with other output tips in accordance with an aspect of the present invention.

According to another aspect of the current invention, the output tip **108** can additionally, or alternatively, comprise a bendable tip cannula **109**. Furthermore, according to yet another aspect of the invention, the output tip **108** can additionally, or alternatively, comprise a disposable output tip **108**, which may or may not (according to various, non-interchangeable embodiments) comprise a cannula, which may or may not (according to various, non-interchangeable embodiments) be bendable. In the case of a bendable tip cannula **109**, it may comprise a pliable material, such as a pliable metal. According to typical implementations of the bendable tip cannula **109**, the bendable tip cannula **109** can be bent at any angle, can have various diameters and lengths, and/or can be packaged, for example, pre-sterilized in a sealed, sterile package.

Regarding such a bendable tip cannula **109**, the pliable material may comprise, for example, a treated stainless steel material. The stainless steel material may be treated to make it bendable and/or to make it more readily bendable without kinking. Following an exemplary treatment of the bendable tip cannula **109** while, for example, the bendable tip cannula **109** is in a pre-bent orientation (or following treatment of the material used to make the cannula before the cannula is formed), the bendable tip cannula **109** can be bent a relatively large number of times from the pre-bent (straight) orientation, while remaining fully, or in another embodiment substantially, or in another embodiment adequately, operable. In a typical embodiment, the relatively large number can be three, four or five, but in modified embodiments smaller or larger numbers can be implemented.

A side-elevation view of an exemplary output tip **108**, comprising an output fiberoptic **107**, a bendable tip cannula **109** and a ferrule **112**, is depicted in FIG. 6. The ferrule **112** may comprise, for example, plastic (e.g., acrylic or polycarbonate) that is, for example, transparent to the laser beam. A cross section of this output tip **108** is shown in FIG. 7. FIG. 8 is a side-elevation view of the output tip **108** connected to the handpiece **78**. Also, FIG. 9 is a cross-sectional view of the assembly of FIG. 8; FIG. 10 a magnified view of portions of the structure of FIG. 9; and FIG. 11 is a schematic representation of the portion depicted in FIG. 10.

As elucidated in FIG. 10, the optical interface can comprise, for example, a physical barrier that is optically transparent, such as a window **114** shown in FIGS. 10-12. The window **114** can be readily removable and field replaceable using an attachment scheme that that does not rely on adhesives or permanent formations, wherein removal of the output tip **108**, ferrule **112**, and/or additional components can provide access to the window **114** for removal or insertion thereof. Although modified implementations of the optical interface may comprise lenses or other optical elements on one or both sides (e.g., proximal and distal sides) of the optical interface, the illustrated embodiment comprises nei-

ther. According to this illustrated implementation and aspect of the invention, lens structure or functionality is not provided on either side of the window 114 to attenuate a risk of, for example, misalignment, leaking, and/or damage when the output tip 108 is inserted, removed or otherwise repositioned.

As can be seen from a review of FIGS. 10 and 11, each of the trunk optical fiber 73, which is shown in FIG. 10 disposed within a channel 73a, and the output fiberoptic 107, which is shown in FIG. 10 comprising a glass fiber 107a encompassed within a jacket 107b (e.g., a Teflon or polyethylene jacket), can be spaced from a corresponding surface of the window 114. In the illustrated implementation, each of the trunk optical fiber 73 and the output fiberoptic 107 can be spaced about 100 microns from a corresponding surface of the window 114. A point on the perimeter of the distal end (i.e., output surface) of the trunk optical fiber 73 can be referred to as a beginning point. Referring to FIG. 11, an angle of divergence A1, measured between the optical axis of the trunk optical fiber 73 and a path of output energy extending from the beginning point to an edge (i.e., perimeter edge) of the proximal end of the output fiberoptic 107, can be about eight degrees. Although the proximal input end of the output fiberoptic 107 does not contact the window 114, intermediate or outer portions of the ferrule 112 do, as can be seen in FIG. 10, to thereby ensure exact positioning of the output tip 108 with each insertion of each output tip 108. In a modified embodiment, a push/twist/lock design, or a click or snap design, can be implemented instead of the illustrated threaded design for securing the output tip 108 to the handpiece 78.

In the depictions of, for example, FIGS. 7 and 10, an air gap 111 is disposed between the output fiberoptic 107 and the bendable tip cannula 109. Furthermore, in the illustrated embodiments of, for example, FIGS. 7 and 10, an air gap 111a is disposed between the distal end of the aiming beam fiber 115 and the proximal side of the window 114 and is further disposed between the distal end of the trunk optical fiber 73 and the proximal side of the window 114. Moreover, in this illustrated embodiment, another air gap 111b is disposed between the distal side of the window 114 and the proximal end of the output fiberoptic 107.

FIG. 12 is a schematic representation of the portion depicted in FIG. 10 according to a modified embodiment, and FIG. 13 depicts an irradiation pattern that may be generated and output from the modified embodiment of FIG. 12. In this embodiment, instead of the aiming beam fiber 115 being configured to deliver radiation to the optical interface (e.g., window 114) at a relatively steep angle as shown in FIG. 10, the aiming beam fiber 115 can be constructed to deliver radiation to the optical interface along a path that is substantially parallel to the trunk optical fiber 73.

The output surface of the aiming beam fiber 115 can be truncated and polished at a non-normal angle so that the output surface directs the aiming beam into the center of the output fiberoptic 107. A point on the output surface of the aiming beam fiber 115 intersected by the optical axis of the aiming beam fiber 115 can be referred to as an output point. With reference to FIG. 12, the angle A2 between the optical axis of the aiming beam fiber 115 and a path of output energy directed from the output point into the center of the output fiberoptic 107 may, for example, be from about 10 to 20 degrees in an implementation wherein the center-to-center separation between the trunk optical fiber 73 and the aiming beam fiber is about 130 to 150 microns and the distance from the output end of the trunk optical fiber 73 to the input end of the output fiberoptic 107 is about 300 to 700 microns. With regard to the illumination pattern shown in FIG. 13, a center 74 of the ring is filled with irradiation from the trunk optical

fiber 73, and the ring pattern 76 corresponds to radiation from the aiming beam fiber 115. With this irradiation pattern, a quality of the ring pattern can be used to determine a quality of the beam or beams.

A core diameter of the trunk optical fiber 73 can be, for example, about 105 microns, and a core diameter of the output fiberoptic 107 can be, for example, about 200, 300 or 400 microns. As embodied herein, the window 114 can comprise sapphire with an anti-reflective coating (ARC) on one or both of its sides. Other structures and materials may be implemented in modified embodiments, and, according to certain aspects, such modifications can maintain a functionality of the optical interface of providing a thermal and/or thermal barrier while providing an optical pathway between the trunk optical fiber 73 and the output fiberoptic 107. For example, a function of the optical interface can be to dissipate heat to protect the trunk optical fiber 73 output end from damage.

FIG. 14 provides examples of a number of typical bendable tip cannulas identified by name, tip type/code, dimensions, other indicia such as the corresponding "kit" and kit part number, and comprising ferrules, which may comprise different colors to indicate different characteristics, and which may be interchangeably affixed to the handpiece 78.

As with typical prior-art implementations, the distal energy output end of the output fiberoptic 107 can exhibit signs of wear or damage after use (e.g., after about 5 minutes of actual lasing time), and thus should be replaced on a frequent and regular basis. The replaceable output tip 108 of the present invention can render such replacements rapid, reliable, efficient, sterile, and convenient. A typical cannula of the invention, such as a typical bendable tip cannula 109, may comprise a one millimeter OD, a 0.1 millimeter wall thickness, and a 2.5 centimeter length, with an inner lumen of the cannula accommodating an output fiberoptic having, for example, a 400 micron diameter, whereby a length of the output fiberoptic protruding distally from the cannula may be, for example, about four to nine millimeters.

With reference to FIG. 15, an electromagnetic energy output device is exemplified in the form of a body-mount implementation. The body-attachment (e.g., wrist mount) implementation of the electromagnetic energy output device 141 can comprise a housing 143 with a body attachment (e.g., a wrist band) 145, a fiber optic 148, and an output configuration. The housing can comprise, for example, a display, such as a touchscreen 156, inputs or controls 159, an electromagnetic energy source such as a laser 161, and batteries 164 which may comprise two sets of batteries. The output configuration is embodied in this example as a handpiece 151 with an actuator control 152 for controlling, for example, an on/off state of an electromagnetic energy source (e.g., laser) and with a fiber optic tip 153.

FIGS. 16 and 17 show perspective front and rear views of an electromagnetic energy output device 171 in the form of a compact, portable assembly that can be carried or mounted with relative ease by a user. The electromagnetic energy output device 171 can comprise a housing 173 with a removable base 175 and a removable spool 177. The removable base 175 can be detachably secured to the housing 173 using any known means for providing a removable affixation, such as, referring to FIG. 19, a protuberance or rib 179 of the base 175 constructed to slidably fit into a slot or channel 181 of the housing 173. In operation, a user can lift the housing 173 above the removable base 175 so that the channel 181 is positioned above the rib 179, as exemplified in FIG. 19. Subsequently, the user can lower the housing 173 in such a way that the channel 181 contacts, is moved around,

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and envelops at least a part of the rib 179, until the housing 173 is positioned on the same plane (e.g., table top) on which the removable base 175 rests.

According to the embodiment of FIGS. 16 and 17, the electromagnetic energy output device 171 further comprises a fiber optic 176, which extends from a point of the housing 173 to the removable spool 177 and which further extends to an output configuration 180. The output configuration 180 is embodied in this example as a handpiece 151 having an actuator control (not shown) for controlling, for example, an on/off state of an electromagnetic energy source (e.g., laser) and further having an output fiberoptic which in the illustrated embodiment comprises a replaceable output tip 183. A foot switch can be used in lieu of the actuator for turning the laser on and off; and it can communicate with the housing 173 using a wireless communication protocol, such as Bluetooth® technology.

The electromagnetic energy output device 141 can be hand-held as can be seen with reference to FIG. 20B. The electromagnetic energy output device 141 can also be wall or pole mounted as shown in FIG. 18, or positioned on a table top as elucidated, for example, in FIGS. 16, 17, 19 and 20A.

The housing 173 can comprise, for example, a display, such as a touchscreen 156, inputs or controls 159, an electromagnetic energy source such as a laser (not shown), and batteries (not shown) which may comprise two sets of batteries. The electromagnetic energy source can be disposed in a lower, rear portion of the housing 173. A power chord can be implemented as an alternative, or in addition to, the batteries. In a modified embodiment, one or more of a size, shape and capacity of the removable base 175 may be altered or enhanced to form an altered or enhanced removable base 175. An example of an altered base, such as discussed below and shown in FIGS. 26A and 26B, may be formed and implemented for carrying the laser and/or one or more additional, optional lasers. As shown in FIGS. 21, 22, and others, when the removable spool 177 is disposed (e.g., attached) in close proximity to the housing 173, an extra length (e.g., one foot) of fiber optic 176 can be stored in a trip-free (e.g., of reduced clutter) and organized fashion. In modified embodiments, the removable spool 177 can be secured to (and, in other modified embodiments, secured and concealed, for example, within) the housing 173, to thereby provide a technician or user with a means of increasing a length of the fiber optic 176 by advancing additional fiber optic 176 from the removable spool 177 toward the handpiece 151 should the need arise. In a modified embodiment, the removable spool 177 can be disposed, but not necessarily attached, outside of the housing 173 and/or in a vicinity of (e.g., adjacent to or inside of) the handpiece 151. Using this technique, a fiber optic 176 length of, for example, 5 to 8 feet can be maintained in the event of damage, such as an overheating occurrence of the optical interface.

In accordance with an aspect of the current invention, the functionality provided by the disclosed arrangement can be accomplished without the necessity of having the fiber optic 176 slidably disposed within the bendable tip cannula 109. Accordingly, and in contrast to the prior-art construction of FIG. 1, the output fiberoptic 107 can be permanently affixed, such as by an adhesive, within the bendable tip cannula 109.

FIG. 26A depicts a particular implementation of a touchscreen and inputs or controls, wherein, for example, the center (e.g., 19.50w) display has left-facing and right-facing arrows for increasing and decreasing various parameters; here power is shown and the dark shaded part on the hemispherical dial shows graphically the degree of that setting compared to the maximum value (cf. a speedometer). An

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Energy Start display can show how much energy has been delivered total, and can be reset to zero after each use. The Energy Start feature does not have a cap and counts the energy delivered. An Energy Total feature, on the other hand, can count down from a preset total amount to be delivered. The Energy Total display can be programmed (or chosen from a preset) to specify a total amount of energy (e.g., deliver in one periodontal pocket 5-10 J; for example, it may take 10-15 seconds and typically will be one continuous shot, to be delivered). If too much energy is delivered, for example, overheating and/or removal of too much tissue may occur; the user typically cannot see within the periodontal pocket, for example, and, furthermore, the patient may not be able to feel the pain in an overdose situation.

Average Power can be calculated in real-time and displayed in J/s. While the figures depict a touchscreen, the functionality of the current system can also be obtained using the user-interface inputs at the bottom of the unit comprising an Enter input and four arrow inputs. The depicted assembly can be wall mounted, wrist mounted (e.g., with a battery, with fewer hard (physical) buttons and more of a display/software driven user interface, and shorter cables/fibers) as exemplified in the depiction and discussion regarding FIG. 15, or belt mounted.

The removable spool 177 can comprise, for example, two parts, as shown in FIGS. 23 and 24, to provide storage and protection to the fiber optic 176. In the exemplary implementation shown in FIGS. 21-25B, the removable spool 177 comprises a spool enclosure 177A and a rubber enclosure 177B. The rubber enclosure 177B can comprise a rubber hub, as depicted, which clips onto the spool enclosure 177A and which controls winding and unwinding of the fiber optic 176. A domed interior of the spool enclosure 177A allows coils of the fiber optic 176 to expand in the chamber. With reference to FIG. 24, in certain implementations fiber optic 176 which is wrapped around the removable spool 177 is unspooled and released as a user pulls the handpiece away from the removable spool 177. Referring to FIG. 25A, during winding, the rubber enclosure 177B (e.g., rubber hub) directs windings of the fiber optic 176 inward and supplies containment pressure. Referring to FIG. 25B, it can be seen that, during unspooling, pulling of optical fiber 176 out of the spool causes the rubber enclosure 177B (e.g., rubber hub) to deflect away from the spool enclosure 177A, allowing the fiber optic 176 within the removable spool 177 to spill out automatically so that the user does not need to manually unwind the fiber optic 176 from the removable spool 177.

The laser module 69 of, for example, FIGS. 25A and 25B, can comprise a diode laser. The diode laser of the system can be disposed near the bottom of the housing 173, and the removable base 175 can serve as a heat sink. Additional lasers can be added into the bottom of the housing 173, into the base 175, and/or, according to the modified implementation shown in FIGS. 26A and 26B, referenced above, a base 186 can be formed (e.g., restructured, as shown, to provide a larger interior) to provide a greater volume for the additional lasers. Also, the base 186 can be formed to have extra ribs or other heat dissipating structures.

In view of the foregoing, it will be understood by those skilled in the art that the methods of the present invention can facilitate formation of laser devices, and in particular diode laser systems. The above-described embodiments have been provided by way of example, and the present invention is not limited to these examples. Multiple variations and modification to the disclosed embodiments will occur, to the extent not mutually exclusive, to those skilled in the art upon consideration of the foregoing description. Such variations and modi-



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fications, however, fall well within the scope of the present invention as set forth in the following claims.

What is claimed is:

1. An apparatus, comprising:  
an excitation source comprising at least one laser diode;  
a handpiece including an energy waveguide having a proximal end coupled to receive electromagnetic radiation from the excitation source and a distal end extending through to an optical interface within the distal end of the handpiece;  
an exchangeable bendable tip cannula including an output fiber optic,  
the bendable tip cannula comprising a steel material possessing a treatment characteristic and a corresponding quality of being more readily bendable without kinking, a wall thickness of at least about 0.1 mm, and a characteristic of being bendable, from a straight orientation to a bent configuration spanning an angle of at least about forty degrees, while remaining fully operational, three times without kinking; and  
wherein the bendable tip cannula is configured for readily exchangeable attachment to the distal end of the handpiece; and  
wherein the output fiber optic is configured to receive the electromagnetic radiation from the optical interface when the bendable tip cannula is coupled to the distal end of the handpiece.
2. The apparatus as set forth in claim 1, wherein the energy waveguide is affixed by an adhesive within the bendable tip cannula.
3. The apparatus as set forth in claim 1, wherein:  
the excitation source is a laser module within a system;  
the energy waveguide comprises a trunk optical fiber; and  
the laser module is directly coupled to the energy waveguide, and the energy waveguide is permanently coupled to the system.
4. The apparatus as set forth in claim 1, wherein the excitation source is a laser module within a diode laser system, and the laser module is directly and permanently coupled to the energy waveguide.
5. The apparatus as set forth in claim 1, wherein the apparatus is configured to output laser energy having a wavelength of about 915 nanometers, about 940 nanometers, about 960 nanometers, or about 980 nanometers, and wherein the apparatus is configured to output the laser energy in a continuous wave or quasi-continuous wave mode.
6. The apparatus as set forth in claim 1, wherein the apparatus is configured to output pulsed laser energy with a pulse duration and a pulse interval.
7. The apparatus as set forth in claim 6, wherein the pulse duration is about 50 microseconds or less and the pulse interval is about 450 microseconds or more.
8. The apparatus as set forth in claim 1, wherein:  
the apparatus is configured to output pulsed laser energy with a pulse duration and pulse interval; and  
wherein the pulse duration can be adjusted independently of the pulse interval.
9. The apparatus as set forth in claim 1, wherein:  
the apparatus is configured to output pulsed laser energy with an independently adjustable pulse interval that can be adjusted independently of the pulse duration.
10. The apparatus as set forth in claim 1, wherein the apparatus is configured to output pulsed energy, a pulse duration may be varied by a user to a greater or lesser degree than a varying of a pulse interval, and the pulse interval may be varied by a user to a greater or lesser degree than a varying of the pulse duration.

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11. The apparatus as set forth in claim 1, wherein the bendable tip cannula is configured to be bendable four times, without kinking and while remaining fully operational, from a straight orientation to a bent configuration.

12. The apparatus as set forth in claim 1, wherein (a) the excitation source is disposed within a system, (b) the energy waveguide is a trunk optical fiber that is permanently coupled to the system, and (c) the excitation source is directly coupled to the energy waveguide.

13. The apparatus as set forth in claim 1, and further comprising a ferrule attached to a proximal end of the bendable tip cannula.

14. An apparatus, comprising:

an excitation source comprising at least one laser diode;  
a handpiece including an energy waveguide having a proximal end coupled to receive electromagnetic radiation from the excitation source and a distal end extending through to an optical interface within the distal end of the handpiece; wherein the excitation source is a laser module within a diode laser system,

the laser module is directly coupled to the energy waveguide, and the energy waveguide extends continuously and without interruption, interface, or coupling from a permanent connection at the laser module all of the way to the handpiece; and

an exchangeable bendable tip cannula including an output fiber optic,

the bendable tip cannula comprising a stainless steel material treated to be bendable or more readily bendable without kinking, a wall thickness of at least about 0.1 mm, and a characteristic of being bendable, from a straight orientation to a bent configuration spanning an angle that would cause an identical cannula of stainless steel to kink, without kinking; and

wherein the bendable tip cannula is configured for readily exchangeable attachment to the distal end of the handpiece; and

wherein the output fiber optic is configured to receive the electromagnetic radiation from the optical interface when the bendable tip cannula is coupled to the distal end of the handpiece.

15. The apparatus as set forth in claim 14, wherein the energy waveguide extends continuously to and through at least a portion of the handpiece.

16. The apparatus as set forth in claim 14, wherein the energy waveguide further extends continuously and without interruption, interface, or coupling from the permanent connection at the laser module all of the way to the handpiece and through substantially all of the handpiece, and terminates at a distal end of the handpiece.

17. An apparatus, comprising:

an excitation source comprising at least one laser diode;  
a handpiece including an energy waveguide having a proximal end coupled to receive electromagnetic radiation from the excitation source and a distal end extending through to an optical interface within the distal end of the handpiece, wherein the apparatus is configured to output pulsed energy, a pulse duration may be varied by a user without varying a pulse interval, and the pulse interval may be varied by a user without varying the pulse duration; and

an exchangeable bendable tip cannula including an output fiber optic,

the bendable tip cannula comprised of a treatment characteristic so as to possess a quality of being more readily bendable without kinking, and comprising steel, a wall thickness of at least about 0.1 mm, and a characteristic of

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being bendable, from a straight orientation to a bent configuration through an angle of at least about ten degrees, without kinking and while remaining fully operational, five times; and  
wherein the bendable tip cannula is configured for readily exchangeable attachment to the distal end of the handpiece; and  
wherein the output fiber optic is configured to receive the electromagnetic radiation from the optical interface when the bendable tip cannula is coupled to the distal end of the handpiece.

**18.** The apparatus as set forth in claim **17**, wherein the energy waveguide is affixed by an adhesive within the bendable tip cannula.

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